Motivations and Challenges for Engineer-to-Order Companies Moving toward Mass Customization

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Abstract. ETO companies are mainly characterized by their ability to provide personalized products to customers. However, the current market trends and economic situation direct them to efficient manufacturing of customized goods. In this regard, moving toward Mass Customization and making a hybrid strategy of ETO-MC can be considered as a proper solution for ETOs. This study aims at investigating this topic using both theoretical and empirical data, and through analyzing the potential motivations for ETOs to move towards MC and the possible challenges they might face during such a transition.

Keywords: Engineer-to-order (ETO), Mass Customization (MC), Motivations and challenges, Product configuration

1 Introduction

Engineer To Order (ETO) is considered as a manufacturing strategy in which all the necessary activities to deliver the product (design, engineering, manufacturing, assembly) are executed after receiving the customer's order [1]. Therefore each product is highly customized and the processes along the value chain differ for each product variant. Nowadays ETO companies are surrounded by several trends such as globalization, margin shrink, increased competition, delivery-time pressure, and turbulent technological advances. To achieve profitable business despite all these challenges, more and more ETO companies have started to pursue innovative strategies and a viable approach towards adapting Mass Customization (MC) in the ETO context. Mass Customization is referred as a *"production principle that emphasizes customized products that do not cost more than mass-produced products"*[2]. Despite of several similarities between ETO and MC, their interdependencies are rarely investigated in the literature. In fact, while traditional MC is focused on defining strategies for Mass Producers (MP) to increase the level of personalization without losing efficiency, ETO companies have dealt with the same trade-off (from a different perspective) trying to keep a high level of customization while increasing their productivity [3]. The few studies in the literature investigating both ETO and MC are mainly focused on the operational level. On the other hand, scarce contribution has been pro-

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vided at the strategic level where there is a lack of support for ETO firms to evaluate the convenience of a shift towards MC [4].
To this end, this study aims at proposing a new term of ETO-MC, which suggests a hybrid strategy to ETO firms combining the characteristics of MC and ETO. Moreover, the paper aims at identification and analysis of possible motivations and challenges that an ETO company might face during its transition toward MC in a value chain perspective.

2 Methodology

With the intent to obtain a comprehensive overview of the topic, two main data sources are used in this study namely literature and case studies. Accordingly, first a set of opportunities and challenges resulting from an extensive literature has been analyzed and collected in a framework for motivations/challenges identification. The proposed classification is based on the distinguished elements of the ETO value chain. In addition, leaving from the results of the literature review, a case study analysis was carried out in order to deepen the findings and improve the results. In this regard, four ETO companies were analyzed. The selection of case studies was mainly based on the four defined independent variables within the study, namely the organization, the characteristic of the product, the market, and the supporting IT Systems. A summary of case study companies is illustrated in Table 1.

Table 1. Case study companies: generalizability of the results

Company	A	B	C	D
Industry	Industrial Steam Turbines	Elevators	Concrete mixing and mineral processing plants	Asphalt plants
Product	Extremely diverse, offering ad hoc technologies for different customer	Slightly Diverse, high degree of commonality among product families	Very Diverse, core technologies are completely different	Moderately Diverse: will to standardize and uniform the technological characteristics
Market (Units/year)	Less than 50	More than 1000	300-500	Less than 300
Supporting IT Systems	Sales Configurator	Design Configurator (Generative)	Design Configurator (Adaptive)	Sales Configurator

3 Findings: identification of motivations and challenges

Based on the data collected from the literature, the motivation and challenges in an ETO-MC environment have been traced back to common areas of concern that can be identified within the processes along the whole value chain [5]. The areas of concern are referred to the domains where the motivations and challenges of a shift toward MC are more likely to happen. They have been defined using a cluster analysis of the collected data. Eventually the final model is developed as a reference structure illustrating the positioning of each part of ETO value chain and their related areas of concern in a transition toward MC (Table2).

Table. 2 ETO Value Chain and areas of concern

Phase	Description	Areas of concern
New Product Development	The process which is delegated to the introduction of new technological solutions matching emerging customers' need and requirements. NPD is critical to the success of ETO firms. A strategic shift towards MC can produce several changes to the performances delivered by this process.	- value creation within a stable solution space - knowledge management.
Sales	A potential customer order in the ETO segment is often initiated by an invitation to tender. The generation of a valid offer document, including mapping of customer requirements, definition of commercial characteristics as well as quotation of prices and lead times, is the general objective within the tender stage [6]. Since the success rate for winning a tender is quite low in the ETO sector, fast and cost-efficient processes are required during this stage [7].	- customer interaction and product configuration - cost estimation - supporting it systems
Order specific Engineering	With the use of configurable BOMs that efficiently implement both generative and adaptive configuration approaches [8], ETO-MC firms are able to adjust the product to fit the single customer's requirements without requiring deep modifications of the product structure. Increases in productivity in ETO-MC strongly relate on this capability and specifically the automation of engineering tasks.	- automation of engineering tasks
Procurement	Procurement obtains the specifications for components and sub-systems from the design function and deals with the relationship with the suppliers of components or sub-assemblies of the product. The effectiveness of procurement in the ETO environment depends upon whether the specifications are correct and appropriate (Caron & Fiore 1995).	- communication and sourcing strategy
Production & Logistics	To remain competitive, a company should synchronize the engineering, manufacturing and procurement processes [9]. That is mainly due to the fact that decisions made during the engineering and development phases affect every downstream process [10].	- operations - warehousing

3.1 Areas of Concern

New product development

Value Creation within a stable solution space: ETO firms addressing MC are able to determine a predefined set of solutions that can be represented within a configurator. This set of solutions is referred to as a solution space. The creation of a predefined product solution space involves the risk that the boundaries of that space are not properly defined [3]. Therefore, from a product design point of view, a transition to MC seems generally to be much more complex for an ETO company compared to a mass producer [3]. Moreover, the simplification of the product designs is an aspect that can have problematic consequences, since it may lead to problems such as "*loss of innovative capability and greater chance of imitation by competitors*" (Hvam et al. 2009). However, the area might contain some potential motivations for an ETO as well such as increased level of commonality and leading to higher number of product variants which can be designed and produced efficiently [8].

Knowledge Management: a crucial requirement that ETO manufacturers have to fulfil in order to shift towards MC is the creation of a "*new and more organized way of structuring the company's product line*" [11]. This can be made by adopting more rational ways of representing product variety (product families, platforms, modularity). Such effort makes "*the knowledge about the configuration system explicit*" [12], facilitating the task of product developers since they dispose of more standardized and clear knowledge of the product they are called to design [11]. It also enables the cross usage of component modules, thus reducing unnecessary redundancy [9], [13].

Sales

Customer Interaction & Product configuration: in an ETO environment, customers requests are constantly translated into technical specifications and production features [10]. In this regard, configurators are considered as a main resource and enabler for MC [14]. In fact, thanks to their systemized product offering, ETO-MC is able to direct customers to internally most easily producible, profitable component combinations [15]. However, the configurator design also implies some challenges. ETO products are often hard to standardize to a degree that allows configuration. This transforms the knowledge-based design to one of the main challenges of an ETO-MC company. [16,17].

Cost Estimation: ETO manufacturers often struggle with significant margin deviations[18]. Accordingly, a considerable high amount of their portfolio generates no or little profit. Such unexpected deviations typically results from poorly made cost estimation. The use of configuration systems is argued as a way to improve the quotation process of ETO products [19]. By calculating budget quotations, the configuration system manages to create sufficiently precise price estimations offered by one company providing a "*more consistent, fastest easier way to enter an order*" [3].

Supporting IT Systems: the rigidity of traditional systems makes it extremely difficult to configure customized products and manufacturing processes. Hence in an ET-MC environment specific BOM needs to be developed for the scope of technical configuration [20]. A knowledge-based system allows configurable BOMs by means of adaptive or generative techniques, they can be flexibly adapted to the single customer own requirements without needing deep modifications to the product structure [8].

Order Specific Engineering

Automation of Engineering tasks: There are several approaches to study the reuse of product and process knowledge with the aim to reduce the time and cost spent on product development thorough automation of repetitive design tasks [9], [21]. The CODP perspective proposed by Wikner and Rudberg [1], underlines the possibility of stocking engineering knowledge. Operationally, this means to find out repetitive design tasks, to standardize the knowledge related to them and to automatize these tasks. An impact of the reduction of repetitive engineering is that their expertise can be used for high-added-value tasks, since time is freed. On the other hand, the leaders of engineering teams are required to have high technical competences *"to follow the thinking of their colleagues when developing a customer specification"*. In addition, they should have excellent social skills "*to encourage colleagues to use existing parameters or to suggest sensible enhancements*" [8].

Procurement

Communication: People within an ETO-MC organization have to understand reciprocal needs and interdependence in a better way, coming to an agreement on the product characteristics that could be varied by the customer, taking into account the material planning [9]. In addition, thanks to the latest IT systems releases, third companies are sometimes allowed to interface directly with the product configuration system, thus improving the performances of the entire supply chain [21].
Sourcing Strategy: with regard to procurement and materials management, "*a firm applying a MC strategy should be able to source and ship small quantities of highly differentiated products efficiently*" [22]. Standard supply chains are generally geared toward handling large quantities of similar or identical products. Mass customizers thus must maintain relationships with more suppliers, spend more time on sourcing market research, and invest in the integration of supply chain management systems.

Production and Logistics

Operations: A successful transition toward MC is only possible if flexible manufacturing processes are supported by an increasing information richness of products and processes, that guarantees a cost efficient and individualized production [23]. Furthermore, when the level of standardization of the product increases, the level of correctness of product information improves as well [9]. Moreover, from a production point of view, the increased standardization of the customized products can lead to motivations, such as reductions of manufacturing costs and amount of error.
Warehousing: The MC strategy implies using some standard modules in the platform of a customized product which eventually leads to an increase in the amount of standardized orders for warehousing, while the dangers of imprecise forecasts will be reduced. In this sense, the risk of not being able to sell purchased items having the technical performances specified during the pre-award phase still exists, but in a smaller scale [3]. However, to avoid long response times, request should be emitted as soon as possible (at the Kick-off of a new project).

4 Empirical findings

Empirical evidences collected from case study analysis provide a broader view toward motivations and challenges of ETO companies on their way to MC in practice. The following findings not only support a part of data collected from the literature but also highlight additional issues that these companies face in practice.

Although the analyzed companies show different characteristics, most of the motivations/challenges entailed by an MC strategy are concentrated in the design stages, new product development (NPD) and Order Specific Engineering (OSE). In particular, NPD, through the application of specific design approaches (modularity, product families, etc.), allows delivering part of the theoretically producible variety at low costs and reduced lead-time. MC approach to OSE can instead lead to savings in case the product needs additional manual working.

A crucial ETO-MC companies' feature is the increased standardization in the engineering phases. Many design activities, associated with the specification of a product, can be automated with the support of IT Systems, such as configurators, and standard documentation. In all the case studies, a reduction of routine/repetitive engineering activities was registered. Nevertheless, even if the companies have already reached a high level of standardization, from the analysis it emerges that additional value could be unlocked from the adoption of design configurator based on parametric design principles.

The interviewed managers pointed out the significant required amount of know-how as a main challenge. In particular, they put in evidence how strong skills are necessary in the design and use of product configurators as tools enabling the transition. However, the development of these capabilities is not immediate. The managers expressed the effort spent in the past to set up these tools and their concern for future developments and integration of this kind of systems. In fact, both the cost and complexity for adapting the configuration software are extremely high; furthermore, these tools express their potential only when they are properly used. Explanatory is the case of company D, which manages to get more standardized orders only when a technical engineer accompanies the sales agent during the customer configuration.

From the analysis, it emerges that a considerable level of integration between NPD, specific engineering and technical support to Sales is required for MC. In the case of companies A and C, engineering team and sales force are in contact on a daily base. In company B, there is full integration between NPD, Sales and OSE. The interaction between Sales and engineering can, indeed, lead to a better matching between customer needs and the product variety that the company is able to deliver without additional engineering.

Regarding production, logistics and procurement activities, the main motivations are conditioned to improvements in the upstream processes. Economies of scale in production and procurement arise, in fact, from a higher degree of standardization in the design phase.

5 Conclusions

This paper aimed at providing ETO firms with a model to clarify the strategic implication when addressing an MC strategy in an ETO-MC environment. Specifically, the model displays a collection of the most critical motivations and challenges entailed by MC, classified by the phase of the ETO process to which they are related.

Based on the results of data analysis, most of the motivations and challenges are concentrated in the design stages (NPD and OSE). In particular NPD, through the application of specific design techniques, contributes to deliver a pre-defined part of all the theoretically producible product variants at a lower cost and a reduced LT. On the other hand, the phase of Order Specific engineering (OSE) in ETO-MC firms is structured to be responsive to non-standard requests that are very differentiated solutions that the firm either is not able or prefer not to represent before the order was received.

The primacy of engineering comes from the evidence that MC is enabled by an increased level of standardization in the design activities. While the theoretical value of this statement is expressed in literature there are rare sources to support the firms which want to assess the practical consequences of the higher standardization implied by MC. This paper provided a deeper insight into the problem presenting a study of the strategic implications of MC thanks to a detailed case study analysis.

The adoption of case studies methodology helped in structuring the perception of managers about the effects of a shift towards MC. Nevertheless, the reduced number of companies limits the applicability outside the specified boundaries of this research. In particular, the generalizability of the results should be tested in the context of small-medium ETO enterprises.

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